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Wide Aspect MWIR Arrays
STATEMENT OF WORK

1 OVERVIEW:

1.1 Summary:

The Navy is initiating a program to demonstrate a new kind of prototype system for ship-based infrared surveillance. It will use a set of eight staring infrared cameras to view the horizon surround and attempt to achieve enough improvement in sensitivity so as to be able to reliably detect a less than 1 W/Ster point source at many miles range. Switchability between two spectral bands is needed, 3.8-4.2 µm and 4.6-4.8 µm, to either take advantage of optimal atmospheric transmission or settle for acceptable transmission with good solar rejection. This Statement of Work concerns the focal plane arrays to be used in these cameras.

The procurement is for three operating 2048x512 mid-wave arrays with a growth path for volume production of 2560x512. Delivery of the operating arrays must be no later than 18 months post award[; the contract may provide for the prospect of delivery within 15 months of award]. Options with this procurement concern the dewar and readout chip for the 2048x512 arrays and the possibility of buying more than three.

F2.4 anamorphic optics being procured separately are being designed to achieve an azimuthal field of view per camera of 48 deg wide if used with 2560x512 arrays, and have a dual elevation field of view of either 10.2 deg or 2.5 deg. With 2048 length arrays in this optics, the azimuthal field of view will be 39.2 deg, which would be sufficient if ten cameras were used. But the eventual objective is to be able to achieve a lower-cost eight camera system while maintaining high resolution and sensitivity for performance, hence the requirement in this procurement for a growth path to 2560x512.

Stabilization platforms also being procured separately are being designed to limit motion to less than a pixel per 100 mSec.

1.2 Historical Background:

Shipboard infrared search systems (IRST's) have, in the past, used scanning technology with a long linear array oriented vertically. This was a way to look up to tens of degrees. But horizontal allocation of detectors is more needed for detection of current low-flying anti-ship cruise missiles. Staring technology offers extended dwell time, faster refresh rate and improved sensitivity, but will require the use of several cameras to simultaneously view the 360 deg of azimuth. If sufficiently small and if mounted with separate windows and stabilization, these cameras can be compatible with modern low radar cross section ship structures. This set of low RCS cameras will be referred to as a distributed aperture system or DAS.

In port against possible terrorist threats there is need to survey the ocean surface from the horizon inward to some 150 ft from the ship or 25 deg below the horizon, but in the primary mission at sea the critical region for infrared surveillance against sea skimming missiles is only a 0.2 deg swath above the horizon. This is a very narrow critical search region, so it is for the missile-detection application that the anamorphic

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factor of 4:1 will be used to shrink the elevation coverage from 10.2 to 2.5 deg. This enhances resolution and sensitivity.

1.3 Sensitivity Quality Factors:

Requirements for high resolution, anamorphic optics are driven by need for very good sensitivity and for blur not much larger than the detector size. The following formulas are used as guides for explaining the requirements:

$$NEI_{BLIP} = h\nu \frac{F\, Q_{blur}^2\, ø_{det}^2}{w_{det}} \sqrt{\frac{x_{opt}\ J_{bkgd}}{\frac{\pi}{4}\, e_{opt}\, e_{cs}\, e_{det}\, t_{int}}}\ , \qquad (1a)$$

$$\sim \frac{1}{w_{det}} \sqrt{\frac{J_{bkgd}}{e_{cs}\, e_{det}\, t_{int}}}\ , \qquad (1b)$$

$h\nu$ = J/Phot = 7.4 & 9.33 $\times 10^{-19}$ at 4.0 & 4.7 µm,
F = geometric mean of az & el F-numbers,
Q_{blur} = blur quality factor = (Blur Size) / ($1.41 w_{det}$)
$ø_{det}$ = geometric mean of az & el detector IFOV's = w_{det}/f
w_{det} = geometric mean of az & el detector pitch, = 25 µm,
J_{Bkgd} = background radiance in $W/cm^2 SecSter$, > $J_{BB}(T_{Bkgd})$,
x_{opt} = $1 + (1/e_{opt}/ - 1)\ (J_{opt}/J_{Bkgd})$ = $1/e_{opt}$ if $T_{opt} = T_{Bkgd}$,
e_{opt} = optical transmission,
e_{det} = detector efficiency,
e_{cs} = cold shield efficiency,
t_{int} = effective integration time including off-chip summation,
f = geometric mean of az & el focal lengths,

$$\text{Aberration Blur Angle} > 2\ \mu\text{Rad} * (\text{FOV in deg})^{1.5} / (\text{F}-.5) \qquad (2)$$

$$\text{80\% Energy Diffraction Blur Spot} = 1.8\ l\ F \approx 8.46\ \mu\text{m} * F \qquad (3)$$

$$\text{Blur Size} = \sqrt{(\text{Aber Spot})^2 + (\text{Dif Spot})^2} \quad (< 1.41\ w_{det})\ . \qquad (4)$$

This NEI formula indicates that detector solid angle IFOV is the single most important system design parameter for achieving good sensitivity. Performance modeling indicates that something on the order of 160 µRad square is needed for detection of the low-signatures anticipated from sub-mach anti-ship missiles at range. The aberration blur formula, Equ 2, in is an empirical fit to many existing lens designs.

1.4 Skin Signature Mach Heating:

The mach-heated part of a missile's skin signature is related to air temperature according to

$$\text{Thermal Part of Contrast Signal} \sim J_{BB}(T_{Bkgd} + T_{Skin}) - J_{BB}(T_{Bkgd}). \qquad (5a)$$

$$T_{Skin} \sim T_{Bkgd}(1 + .175\,\text{Mach}^2). \qquad (5b)$$

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This decreases with temperature roughly in proportion to background radiance. BLIP NEI, Equ 1, also gets smaller in cold backgrounds, but only in proportion to the square root of background radiance. This means that to maintain signal-to-noise ratio in cold backgrounds it is necessary to increase integration time, ideally maintaining wells at about half full.

1.5 Scene Backgrounds:

Background scene air temperatures in the regions where US Navy ships operate generally fall within the range from freezing and a little less than 100F. This is the 98 percentile air temperature range in the NSWC/DD R384 plus Littoral 1320 data base sets. Table 1 indicates the wide range of operating conditions from low photo current to rapid well filling that this range of environmental scene temperatures places on the focal plane array. Several previous demonstration programs have failed because of the low-flux injection efficiency problem.

Table 1: Photo current and Well Capacity Integration Times. The spectral bands are blue = 3.8-4.2 μm and red = 4.6-4.8 μm.

Spectral Band	Elect / mSec		mSec for 8 M Elect	
	blue	red	blue	red
30 degF	.12	.22	64	36
100 degF	.76	1.1	10	7.5
130/100 degF	1.1	"	7	"

$$\text{F-no} = 2.4,\ e_{cs} = 80\ \%,\ e_{eff} = 75\ \%,\ T_{Lens} = T_{Bkgd}$$

$$N_{Bkgd\ Elect} = e_{det}\, x_{opt}\, e_{opt}\, (J_{bkgd}/h\nu)\, \frac{\pi}{4}\, (w_{det}/F)^2\, t_{int}, \qquad (6)$$

To this must be added the effects of solar loading and clutter. The processor will switch the spectral filter to the red 4.6-4.8 μm band when solar clutter is noted. This spectral band is relatively immune to solar as opposed to the high-transmission blue band, but, still, the solar illumination can be so intense that in some cases detectors will saturate even with large well capacity, short integration time and use of the red band.

Subjective experience is that solar lighting of clouds is intense and structured, and this is in fact the dominant issue limiting detection of air targets with the infrared. But for sea skimmer missile detection, it is the horizon scene that has to be addressed especially carefully, and for this the solar effects can be placed in several categories. Design has to be for the difficult cases to detect a dim but persistent point viewed against structureless sky within a few pixels above the water line or, as a last resort, a dim point just below the horizon line and viewed against water, possibly with negative contrast.

Aerosol forward scattering of solar radiation, either direct solar radiation or radiation off the ocean surface, are the first two categories of solar radiation. Usually there are no clouds visible in the first 1.5 to 2 deg above the water line, but instead aerosol forward scattering may reduce signal contrast and add flux loading. This is anticipated not to be a significant factor in practice especially given that the red band will be used whenever the presence of solar is discerned by the control processor. The third row of

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Table 1 gives the results of a Modtran calculation for the direct scattering off aerosols under the sun direction and for average atmospheric transmission. This solar forward scattering off aerosols can add 15 % to the blue band effectively raising the hot 100F background to 130F. But for the red band there is only a .03 % effect compared to the hot 100F background.

Solar radiation off the ocean surface can be described as bounded by two limiting cases. With the sun above 50 deg in elevation, the swath of radiation off low sea state waves can be very wide, much wider than the 48 deg azimuthal field of view of a single DAS surveillance camera. On the other hand with the sun at only 5-10 deg in elevation, the swath of the surface-reflected radiation shrinks to a half-width of <20 deg with particularly high intensity as much as 1-10 % of the direct solar illuminance and highly polarized. There are two components to this surface reflected solar radiation - the mean value which can effect signal contrast, and the wave spatially varying part which can act as obscuring clutter - and optical blur will spread both upward into the first pixel or two above the water line. So in regions below versus above the water line, or from directly under to away from the solar direction, the scene to be viewed may have dynamic range beyond the capability of the large-area focal plane array even with the red band.

In operation the first attempt at array operational settings for handling this problem will be to shorten integration time to prevent saturation just below the water line but then attempt to still have BLIP sensitivity just above against cool sky. This will require read noise as low as the shot noise for wells only a small fraction of full but ultimately will be limited by spatial nonuniformities. This suggests a 15 bit dynamic range and very good non-uniformity correction - detector averaging, two-point plus one-point update, and running temporal NUC. And because residual nonuniformities are proportional to well size, the specifications given below attempt to extend dynamic range by achieving lower electronic noise than by higher well capacity. The optics is being designed to offer elevation stepping, either for sub-pixel resolution or for detector averaging.

For the extreme scene cases the below specifications ask for capability to time share integration times, that is, to use alternately short versus long integration times for the whole array to look first at the water and then the sky with an array that does not blur and with control over the A/D least significant bit.

1.6 Target Motions:

The attacking inbound missile should usually display negligible angular motion, either horizontal or vertical, when viewed from the ship. At range, though, the missile may not yet have found the ship and could have a heading error that might make it blur across pixels if the surveillance camera attempts to use long integration time for sensitivity. This blurring may not impede detection if the missile is viewed at a large off-nose viewing angle and is bright. A rough indicator of the bounding geometry here is that most airframes tend to fly a little nose up by 5-10 deg. So they are in a bright side view only if the azimuthal heading error is greater than 10 deg. For heading error <10 deg it remains dim and detection will be impeded by blurring. For a nominal 10 km range and a DAS azimuthal resolution of 340 μRad this geometry puts an upper limit of 100 mSec on integration time. The stabilization system is being designed for this time constant.

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1.7 Declaration Processor and Other Frame Rate Issues:

A search radar can use range, Doppler, range gating, matched-filter and transmit power as tools to enhance signal versus noise or clutter. The discriminants available to an infrared search system, on the other hand, are relatively limited. Small distant missiles will be unresolved, but the infrared system can and must make good use of high angular resolution to spatially discriminate against scene clutter. Basically, after matched spatial filtering, a background-normalized CFAR threshold is used to pick out bright points in the scene. These are called “detections” and are passed to a track processor that uses temporal and signal intensity information to decide final “declarations.” The main declaration discriminant is persistence processing in one form or another, and an unusual possibility not yet fully evaluated is to try to take advantage of scintillation. Scintillation increases the received signal intensity of a point-source about half the time, so the persistence algorithm could look for a 50 % reappearance rate. Scintillation correlation times are often fast, suggesting that frame rates of 30 Hz or more could be of benefit for this kind of declaration processing.

Other factors that set need for fast frame rate are off-chip summation and the possibility of using the arrays to evaluate a step-stare approach for achieving the wide azimuthal field of view. Kill assessment, on the other hand, can probably be accomplished with fairly slow frame rate information.

1.8 Lens Elevation LOS Stepping:

Modest image stepping of up to 1.5 times the detector pitch will be achieved by piezoelectric drive displacement of a component or a set of components in the compound lens. The objective is to use this stepping in either of two ways. Successive frames with half pixel elevation displacement can be use to achieve super-resolution and minimize blurring upward of bright horizon line. For this the array readout may need to be two rapid frames followed by a pause. Or if dual integration times are used as well to bracket scene dynamic range, the array readout may need to execute two frames with short and then long integration time followed by another similar pair and then perhaps a pause. Successive frames with whole pixel displacement can be used for non-uniformity and bad detector correction.

2 PHYSICAL AND INTERFACE CONFIGURATION REQUIREMENTS:

2.1 Array Configuration:

2048x512 detectors with 25 μm pitch and >80 % fill. The basic configuration for the silicon readout chip must match this geometrically, use multiple readouts along the 2048 direction and provide multiplexed analog or digital output from the dewar. See Option 2.

2.2 Dewar Configuration:

The basic dewar must accommodate the 2048x512 hybrid array with 3.8-4.8 μm spectral filter and a well-displaced, high-efficiency F2.4 cold shield positioned at approximately 80 mm from the array. The window and dewar must be permanently sealed with cooling provided by closed cycle refrigeration. See Option 2.

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2.3 Uncooled Filter Wheel:
A three-position remotely operable filter wheel must be placed directly in front of the dewar window. This is for a 3.8-4.2 μm blue filter, a 4.6-4.8 μm red filter, and a 4.5-4.8μm red filter with polarizer. The dielectric interference layers or at least the log-wavelength band edge must be facing the dewar and the mechanical fit must be as flush as possible to prevent entry of stray out-of-band radiation.

2.4 Calibration Wheel:
A three-position remotely operable calibration wheel must be placed directly in front of the filter wheel. One position is an open setting for normal operations, another a thermo-electric element for two-point nonuniformity correction and the third a defocusing element for one-point NUC. The Contractor shall supply and control the TE element and shall also supply a defocusing element. The latter must spread otherwise focused point radiation over an approximately 10x10 detector area with no significant attenuation of radiance on the focal plane. Government may decide that a columnar micro lenses is preferable for defocusing so as to achieve one-dimensional defocus parallel to the unusual knife-edge horizon scene, and if this choice is made, Government will supply the defocusing element.

2.5 Lens Mating:
The Contractor shall perform physical mounting and dewar design, subject to Government approval to assure compatibility with the separately-procured lens.

2.6 Cryocompressor, Vibrations and Coolant Line:
The cryocompressor must be of the dual opposing piston type to minimize vibrations, and the coolant line may need to be long. The final design of mounting position and orientation must be approved by Government to assure packaging and weight distribution compatibility with the separately-procured stabilization system.

2.7 Weight and Size:
The Contractor's design shall minimize the size and weight of the dewar compressor and electronics. These are to be reviewed and approved by the Government at PDR and CDR. See Option 2.

2.8 Video Stream, Headers and Synchronization Signals:
Inputs must be sufficient for remote control of all array setting, read, calibration, off-chip summation and piezo micro-stepping conditions. The digital video output stream must include a header segment that summarizes all array parameter conditions. An additional output needed for piezo micro-stepping must provide end and beginning of integration time, and frame count in the chosen piezo drive sequence. The power electronics for the piezo LOS drive is a Government responsibility, but timing signals for this drive have to be supplied by the array electronics.

3 ELECTRONIC AND PERFORMANCE REQUIREMENTS:

3.1 Injection Efficiency and Dark Current for Cold Backgrounds:
Good injection efficiency and low dark current must be achieved against 30F backgrounds viewed through F2.4 optics.

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3.2 Electronic Noise:

Electronic noise must be 750 carriers or less per read referred to the input. Setting of the A/D least significant bit relative to electronic noise must be controllable, and off-chip summation must not add to the square root dependence of noise versus the number of summations. 250 noise electrons would be preferred if spatial non-uniformity correction could be commensurate.

3.3 Integration Time and Well Capacity for Cold Backgrounds:

The arrays are required to be able to operate with integration times as long as 100 mSec in low-flux backgrounds.

3.4 Well Capacity for Hot Backgrounds:

Well capacity of 10 million carriers is required. This is defined as the level at which nonlinearities set in to such a degree that nonuniformity correction would no longer be viable.

3.5 Dynamic Range:

The array read and output digital electronics must be able to handle signals form the < 750 noise carriers to the 10 million full well, a dynamic range of > 82 dB. The minimum A/D range for this Statement of Work is 14 bits, which would be 84 dB if noise were dominated by the least significant bit. An A/D range > 14 bits and a dynamic range more than 82 dB with lowered noise level are preferred.

3.6 Dual Integration Times for Mitigation of Solar Loading:

An input setting is required to allow operation with a toggling succession from frame to frame of two different integration times.

3.7 Anti-Blooming and Charge Spreading to Limit Solar Loading:

The horizon scene can sometimes be essentially a bright knife edge, and charge spreading must be less than what can be expected for carefully designed optics. Charge and signal spreading in the array, the read electronics, the dewar window and filters must be no more than 2 %.

3.8 Nonuniformity Correction and Residual Spatial Noise:

Both two-point and one-point nonuniformity correction must be executable by remote command, and there must be enough memory to retain and use at least two sets of coefficients plus bad-detector map. Raw uniformity must be ≤ 5 %, and the residual nonuniformity after two-point correction must be ≤ .1 % global and ≤ 0.05 % local before detector averaging or additional one-point corrections

3.9 Operability:

There must be fewer than 5 % bad detectors. Given adjacent detector averaging, the greater concern in this procurement is for clustering of three or more vertically adjacent bad detectors (in the 512 direction). One of the three 2048x512 arrays to be delivered must have fewer than 1000 occurrences of such three-or-more elevation bad clusters.

3.10 Bad Detector Correction:

There must be two modes of operation for this function. In the straight staring mode bad detector correction must be made by a standard average of nearest neighbors. In

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the LOS stepping mode of detector averaging, bad detectors must be replaced. For two LOS detector averaging, for instance, the normal output is 1/2 the sum of the outputs from two elevation nearest neighbors. But if one of them is bad, the output must be just that of the good detector. A map of bad pixels must be provided on the video output at the time of each two-point NUC calibration.

3.11 Off-Chip Summation With or Without Detector Averaging (TDI):
The array readout electronics must include capability for off-chip summation of 2, 4 or 8 sequential frames, the final output being one summed frame of video for fixed line-of-sight pointing. Another required mode of operation is detector averaging and correction via off-chip summation synchronized with elevation stepping. As mentioned, the optics will be capable of piezo-drive LOS stepping by one elevation pitch spacing, and the array circuitry must output timing signals as needed for the elevation stepping.

3.12 Readout Modes:
The array clocking must have independently controllable integration and frame times and must be able to operate with or without off-chip summation. The off-chip summation must be executable either for extending effective integration time or for averaging vertically adjacent detectors or for both. The electronics must also accommodate super resolution by supplying another case of timing signals for the piezo driver.

3.13 Performance Summary:

array dimensions	≈ 2" x 0.5" active area
number of detectors	2048 x 512 (or longer)
detector pitch	25 µm, or very close to this
operability	> 95 %
fill factor	> 85 %
quantum efficiency	> 75 %
blooming & cross talk	≤ 2 %
well capacity	linear response to 10 million carriers
spectral band	3.7 - 4.9 µm detector responsiveness
	3.8-4.8 µm for cooled filter
	3.8-4.2 µm & 4.6-4.8 µm for uncooled filters
readout	whole-frame not staggered
video output	post summation with bad pixel correction, digital with headers
integration time	0.1 to 100 mSec controllable independent of frame rate
dual integ. times	ability for array to toggle continuously between two t_{int}
frame rate	30/sec or slower, controllable and salvable
electronic noise	< 750 e- required, ≈ 250 e- desired
dynamic range	82 dB & 14 bits required, greater desired
injection efficiency	>90% against 30 °F bkgd with F2.4 optics and low dark current
raw nonuniformity	≤ 5 %

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2 point NUC	≤ .1 % global, ≤ 0.05 % local, residual nonuniformity when encompassing large well filing range
1 point NUC	maintain 2-point NUC performance for extended time
detector averaging	reduce residual nonuniformities by $\sqrt{2}$ beyond NUC
temporal NUC	not Contractor responsibility
dewar design	F2.4 cold shield at 80 mm
	3.8 - 4.8 internal cooled filter
filter wheel	3.8-4.2 vs 4.6-4.8 just in front of dewar window
calibration wheel	two-point TE, one-point defocus and open

4 FINAL ACCEPTANCE TESTING:
The Contractor must demonstrate array operation satisfying all the above performance and mode specifications. This may be done either with a Contractor-supplied or the Government specially-designed lens. The Contractor shall provide all equipment needed for this testing including 30F and 100F extended and hot knife-edge sources. If a Contractor-supplied lens is used, a means must be provided for demonstrating adequacy of the output timing signals for the two modes of piezo-driven LOS micro stepping.

5 SUPPORT AND MAINTENANCE: The Contractor shall provide repair or replacement at the factory of any failed part or function of the operating arrays. This is to be for a period of 18 months after delivery and include mechanical, electrical, software or vacuum components or integrity.